ESTO 2006 Technology Conference –
Suborbital Science Session, June 26-29, 2006

First Observations with a New Observing System of Stacked Multiple UAVs for Observing the Effects of Air Pollution on Clouds and Climate Forcing

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&

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The Maldives Autonomous Unmanned Aerial Vehicle Campaign (MAC)

06 March - 01 April, 2006

Science Team: Scripps Institution of Oceanography

V. Ramanathan *(PI)*
H. Nguyen *(Mission Director)*
C. Corrigan *(Aerosols)*
M.V. Ramana *(Radiation)*
G. Roberts *(Lead Instrument Scientist)*

Flight Team: Advanced Ceramic Research

A. Mulligan *(Project Director)*
M. Patterson *(Project Manager)*
L. Wardell *(Project Leader)*
P. Corcoran *(Pilot-in-Command)*
E. Hooper *(Pilot)*
R .A.G. Pineda *(Pilot)*

The Maldives Autonomous Unmanned Aerial Vehicle Campaign (MAC)

06 March - 01 April, 2006

Goals and Objectives

MAC will further develop light-weight AUAVs as affordable, viable, and cost-effective observing platforms for environmental sciences

The particular emphasis of MAC is to demonstrate that light-weight AUAVs can fill an important and vital gap in our measurement capability by sampling cloudy layers from all sides simultaneously (Flying AUAVs in stacked formation)

The fundamental science objective of the MAC is to provide new insight into how aerosols and clouds regulate the planetary albedo, with particular emphasis on how anthropogenic aerosols modify the albedo of cloudy skies (the so-called indirect effect)

Specific MAC objectives:
Measures the aerosol radiative forcing and cloud forcing directly from observations; and subsequently relate the measured forcing to in-situ aerosol and cloud microphysical measurements from AUAVs (via climate models)

Provides vertical and horizontal profiling in the atmosphere to compliment surface measurements taken at MCO-*Hanimaadhoo* and MCO-*Gan*.

MAC Specific Goals and Objectives

Technology Demonstration:

3 UAV Stacked Flights with instruments for near simultaneous measurements* of aerosols, BC, cloud microphysics and solar radiation fluxes in cloudy and polluted atmosphere.
***(The 20-20 vision)**

Science Demonstration:

1. Direct measurement of solar absorption in the atmosphere
2. Linking aerosols with atmospheric solar absorption and cloud microphysical properties
3. Linking aerosols and cloud microphysical properties with cloudy sky albedos
4. Linking aerosols and BC with cloudy sky absorption
5. Vertical profiles of aerosols, clouds and radiation fluxes

Aerosol Concentration and Distribution
Incoming & Reflected Solar Radiation

The MAC Observing System

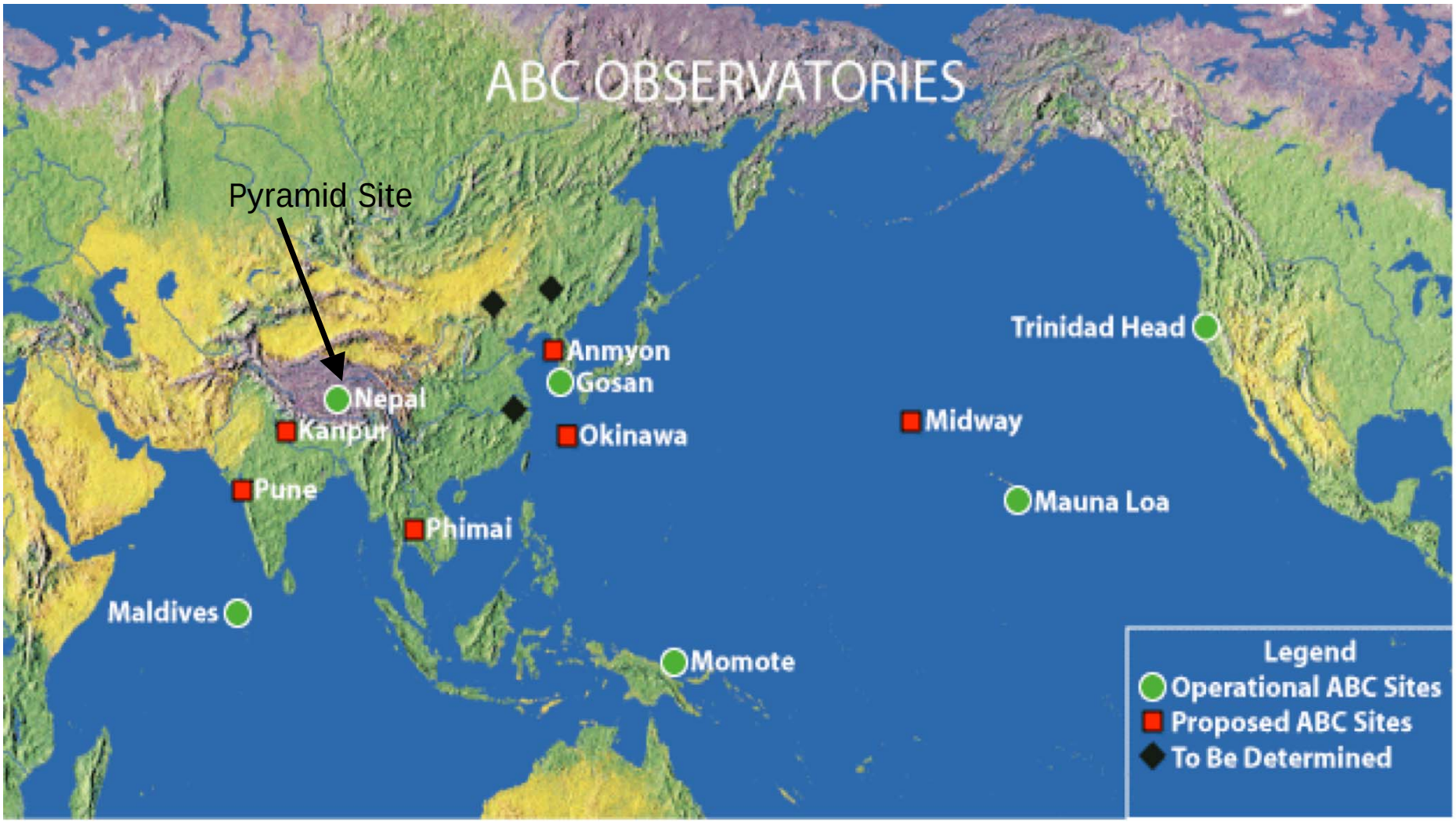
Cloud Drop Size & Concentration
Total Liquid Water Content

Aerosols & BC Concentration and Distribution
Incoming and Reflected Solar Radiation

Lidar, CCN Spectrometer,
Aerosols, BC, Radiometers

Project ABC MCO-H

ABC Observatories

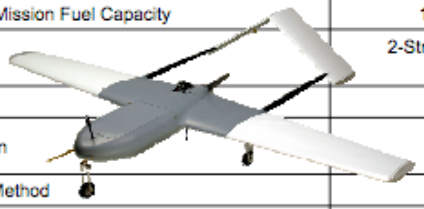



Hanimaadhoo Island
ABC Observatories
village
Airport

Manta B Specifications

Parameter	Value (U.S.)	Value (Metric)
Maximum Gross Takeoff Weight (MGTW)	52 lbs	23.5 kg
Nominal Mission Takeoff Weight (NMTW)	45 lbs	20.4 kg
Nominal Mission Endurance (87 octane gasoline)	6+ Hours	
Fuel Type	50:1 Gasoline/Oil Pre-Mix	
Airspeed (Cruise @ NMTW)	39 - 70 knots	72 - 130 kph
Airspeed (Dash - Level Flight @ NMTW)	70 knots	130 kph
Airspeed (Max. Endurance @ NMTW)	39 knots	72 kph
Airspeed (Stall @ NMTW)	35 knots	64 kph
Airspeed (VNE @ NMTW)	110 knots	203 kph
Navigation	DGPS/GPS, DGPS/GPS/INS[1]	
Service Ceiling	16,000 feet MSL	4,870 meters
Launch	Wheeled, Vehicle Based, or Launcher (Coming Soon)	
Recovery	Parachute or Gear	
Payload (EO)	PTZ Daylight Camera	
Payload (IR)	PTZ IR camera	
Command and Control Radio (C2)	Up to 2 Watt, Discrete/Frequency Agile, Military Band / ISM Band Radio Modem (TX/RX)	
Command and Control Radio Range	15-20 nm, Line of Sight (LOS)	24-32 km, Line of Sight (LOS)
Video Transmitter	2 Watt (Optional 5W), S-Band FM Video TX With Optional 19.2kbps Data Carrier	
Video System Range	15-20 nm, LOS	24-32 km, LOS
Payload Capacity	Up To 15.0 lbs	Up To 6.8 kg
Onboard Power	BA5590 LiSO2 Battery (One or two batteries can be installed)	
Onboard Power Capacity	14.4V, 15 or 30 AH	
Nominal Mission Fuel Capacity	1.9 Gallons	7.2 Liters
Engine	2-Stroke Reciprocating Gasoline Engine (87 Octane) Reverse Rotation	
Ignition	Electronic, Capacitive Discharge	
Propulsion	18x12, Tractor Propeller (In Reverse Rotation)	
Starting Method	Hand-Held Electric Starter (12V)	
Shipping Container Size	49" x 52" x 24"	1.24m x 1.3m x 0.61m

[1] - GPS/INS option available Q1, 2006



advanced ceramics research

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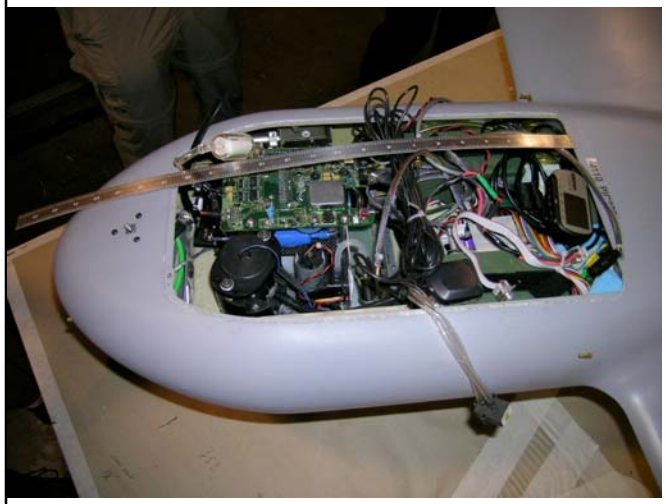
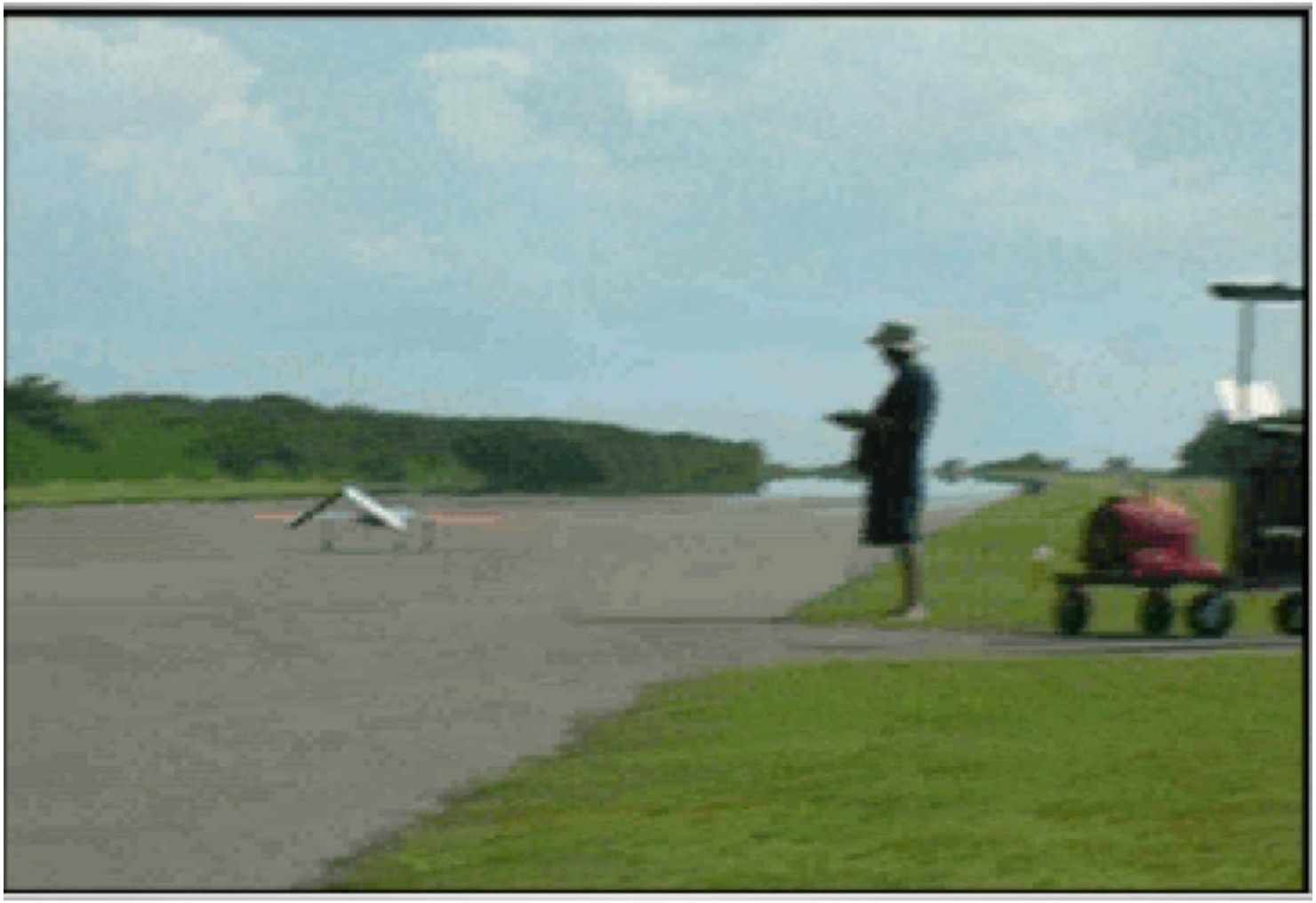
MAC Lightweight Instrumentation

Instruments	Above Cloud (AC)	In-Cloud (IC)	Below Cloud (BC)
Aerosol			
Total CN (CPC; >0.01 µm)	√		√
Size distribution (OPC; 0.3-3.0µm)	√		√
Black Carbon (Aethalometer; 370, 520, and 880nm)	√		√
Radiation			
Up/Down Pyranometer (0.3-2.8 µm)	√		√
UP/Down PAR (0.4-0.7µm)	√		√
Clouds			
Cloud droplet probe (1-50 µm)		√	
Liquid water content probe		√	
Turbulence			
Gust probe		√	
Met. Parameters (T, RH, P)	√	√	√
Aerosol inlet + flow splitter + cyclone	√		√
Data Acquisition system	√	√	√
Video Camera + Downlink		√	
Miscellaneous + Batteries	√	√	√
Total weight	**5.4 kg**	**5.3 kg**	**3.9 kg**



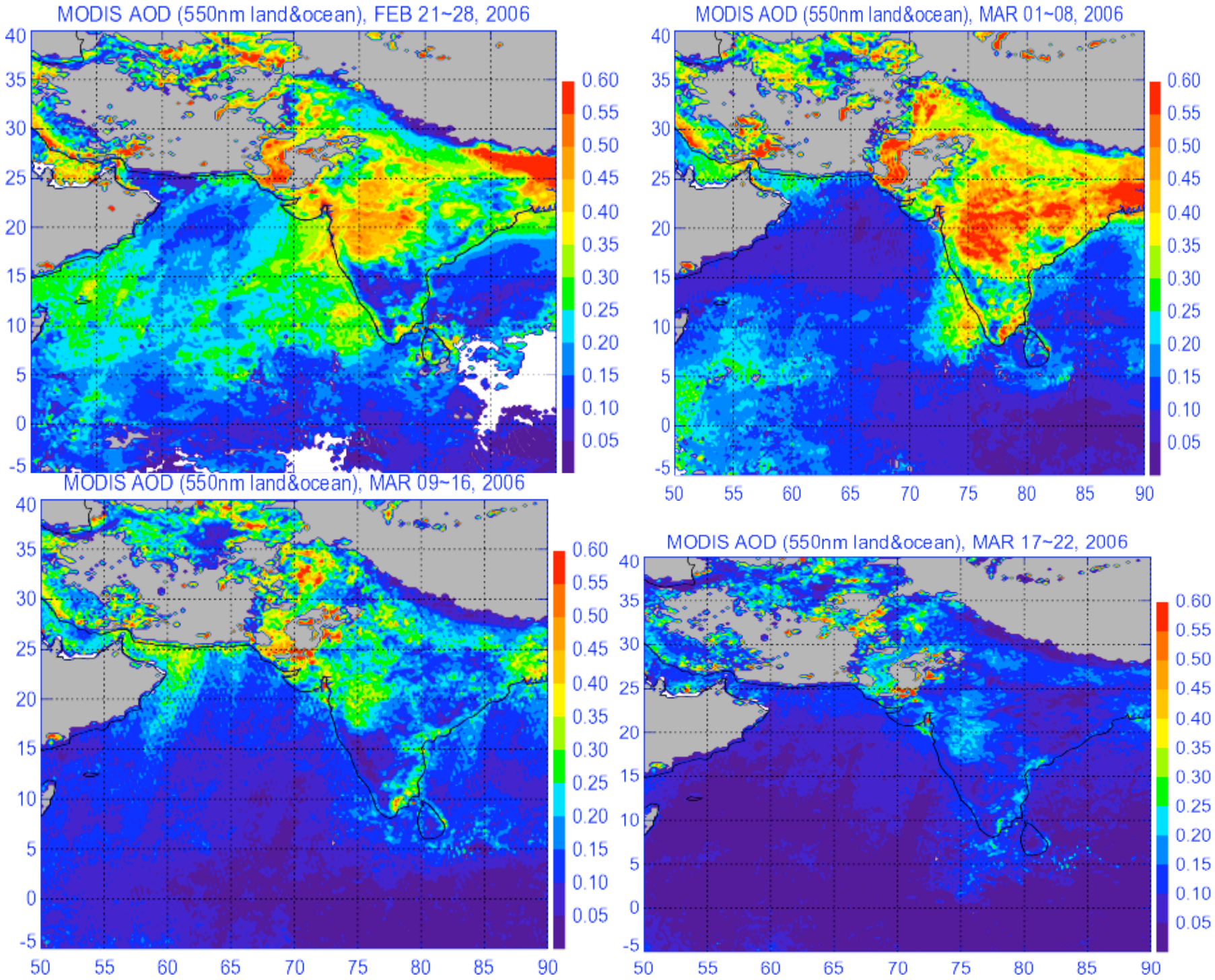


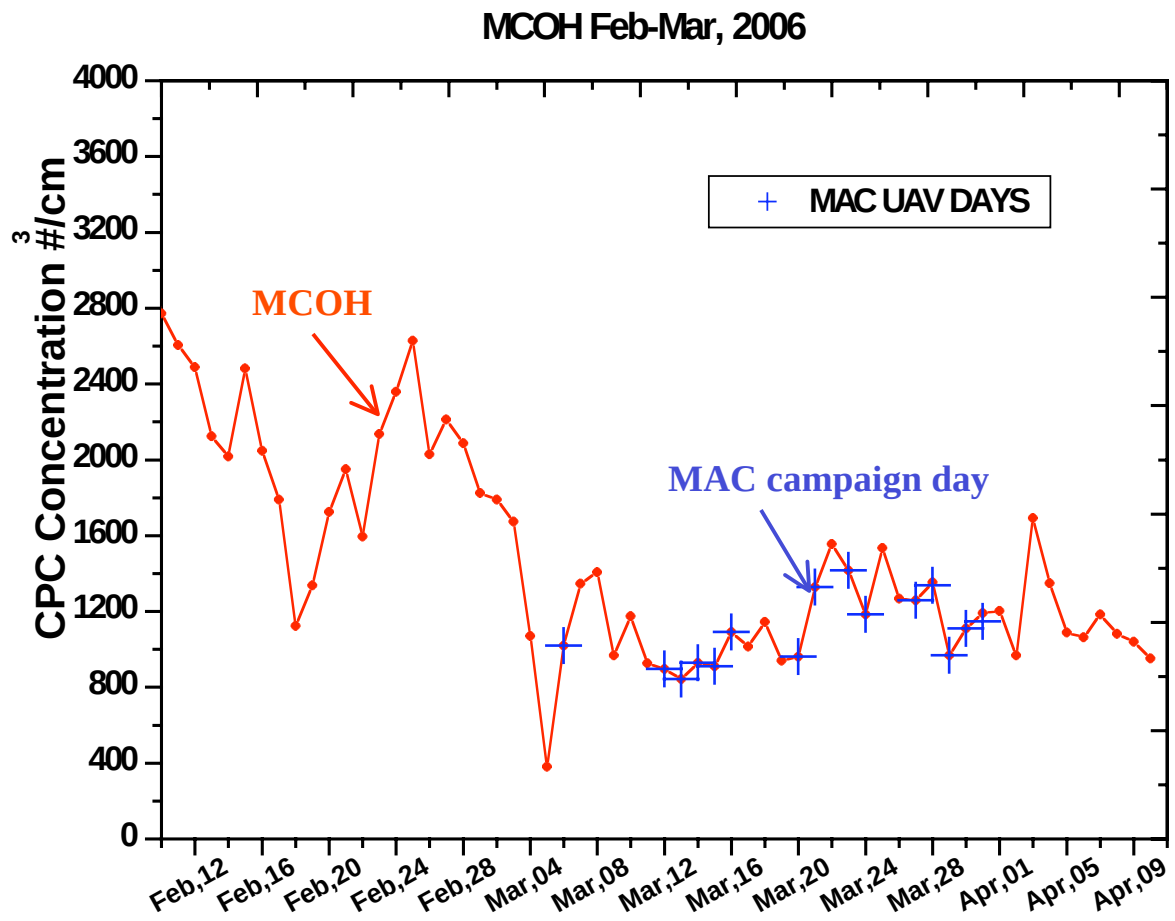
MAC flight summary

Total number of missions	**= 19**
Total flight hours	**= 126 hrs**
Total takeoffs	**= 55**
Total landings	**= 54**
3UAV's in stacked formation missions	**= 10**
2UAV's in stacked formation missions	**= 7**

MAC scientific data summary

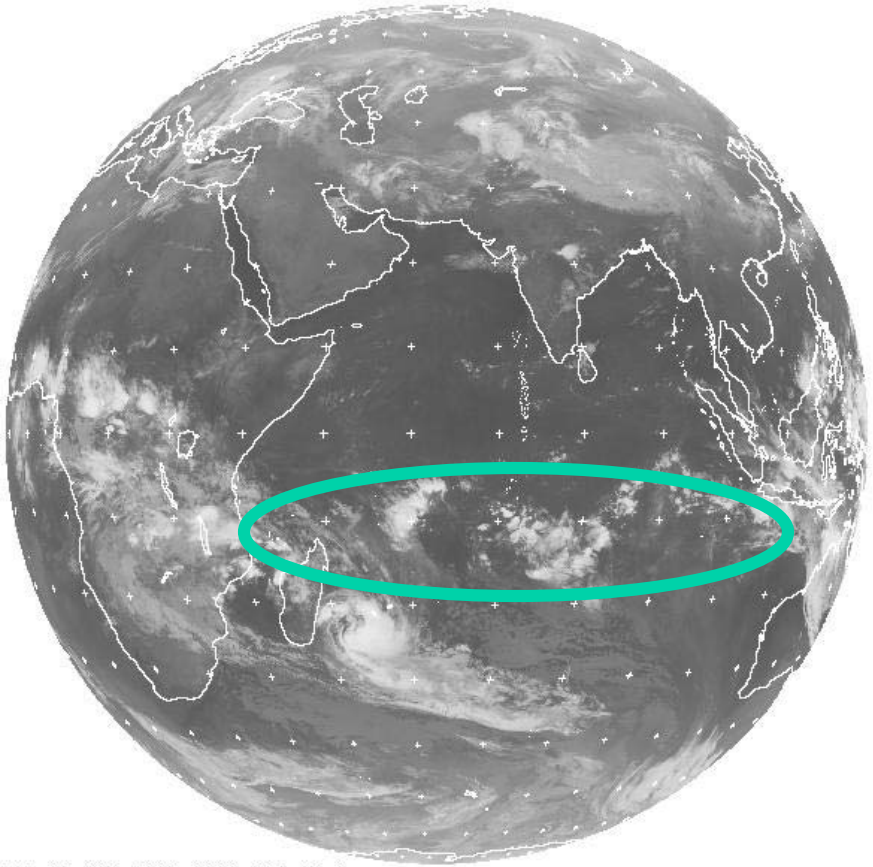
Total hours of aerosol measurements	**= 70 hrs**
Total hours of aerosol vertical profiling	**= 15 hrs**
Total hours of Black Carbon measurements	**= 45 hrs**
Total hours of Black Carbon profiling	**= 27 hrs**
Total hours of clouds probing	**= 39 hrs**
Total hours of absorption measurements	**= 27 hrs**
Total hours of albedo measurements	**= 70 hrs**
Total hours of wing to wing comparison flights	**= 2 hrs**


MODIS AOD (550nm land&ocean), FEB 21~28, 2006
MODIS AOD (550nm land&ocean), MAR 01~08, 2006
MODIS AOD (550nm land&ocean), MAR 09~16, 2006
MODIS AOD (550nm land&ocean), MAR 17~22, 2006
40
35
30
25
20
15
10
5
0
-5
50
55
60
65
70
75
80
85
90
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05


MCOH Feb-Mar, 2006
CPC Concentration #/cm3
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
MAC UAV DAYS
MCOH
MAC campaign day
Feb,12
Feb,16
Feb,20
Feb,24
Feb,28
Mar,04
Mar,08
Mar,12
Mar,16
Mar,20
Mar,24
Mar,28
Apr,01
Apr,05
Apr,09

March 7 2006

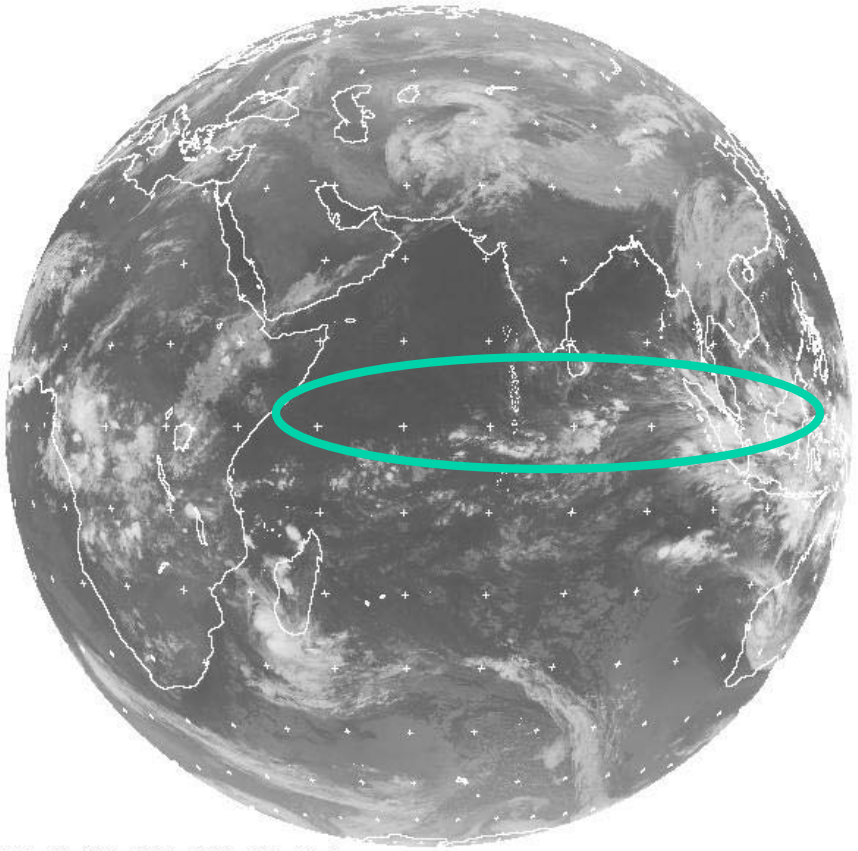
ITCZ was south of Equator



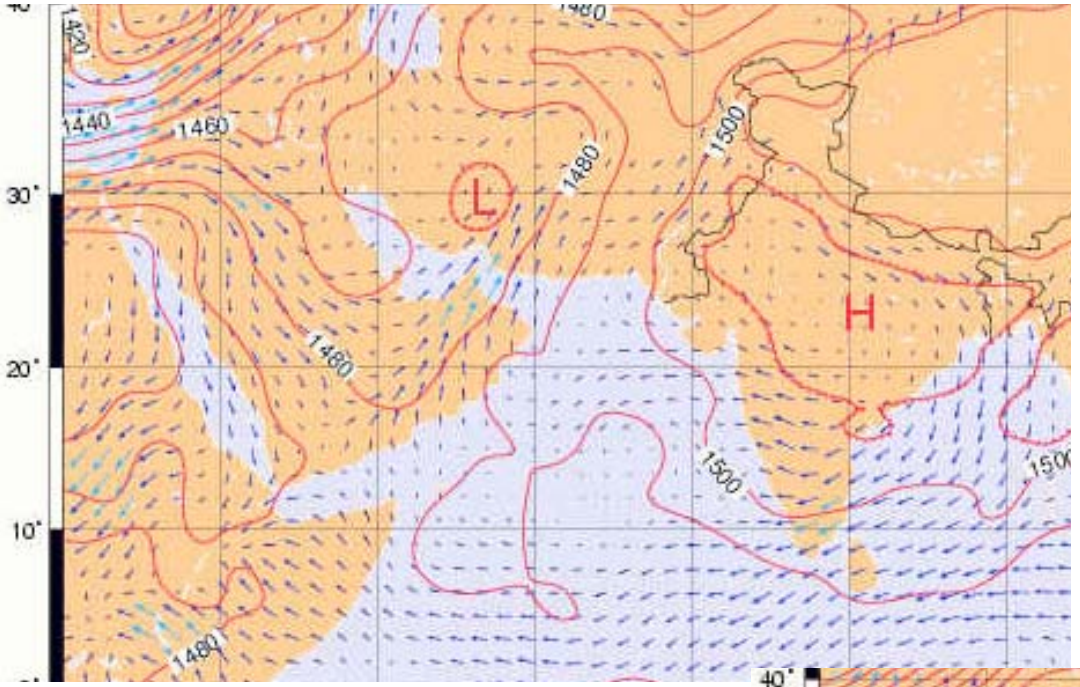
MET5 07 MAR 2006 0000 BNW IR 0

March 31 2006

Northward shift started

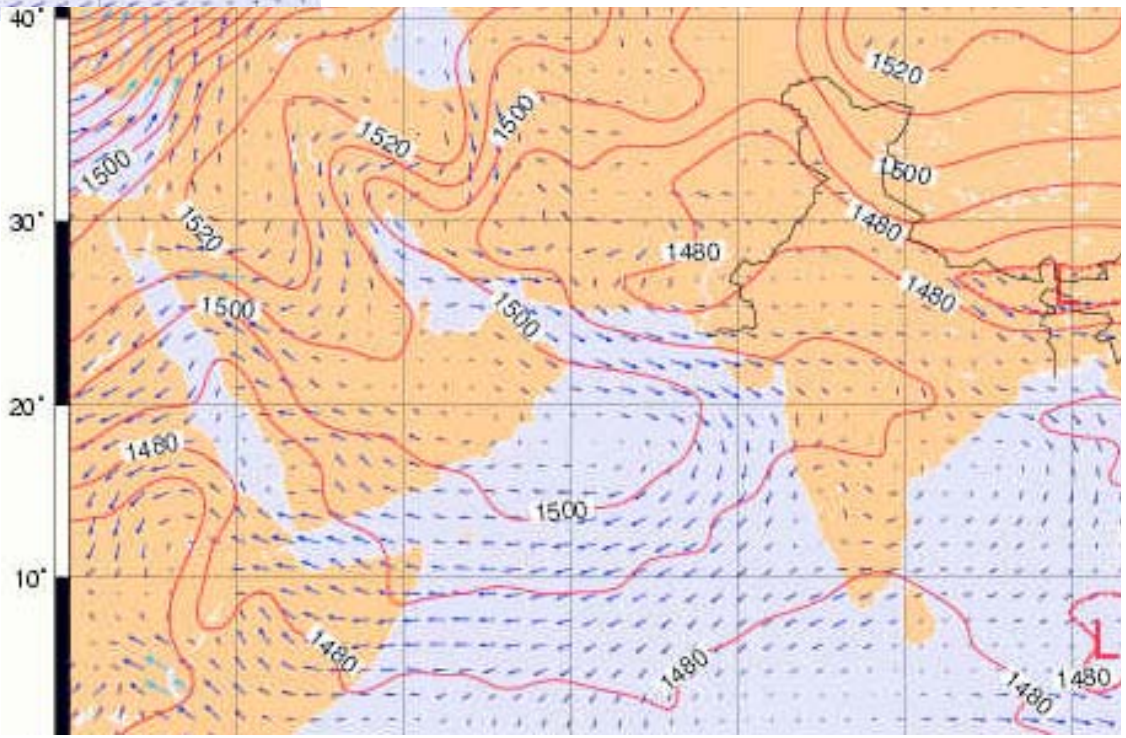


MET5 30 MAR 2006 2100 BNW IR 0



March 19 2006
850 mb winds

Termination of S Asian Pollution Few days later



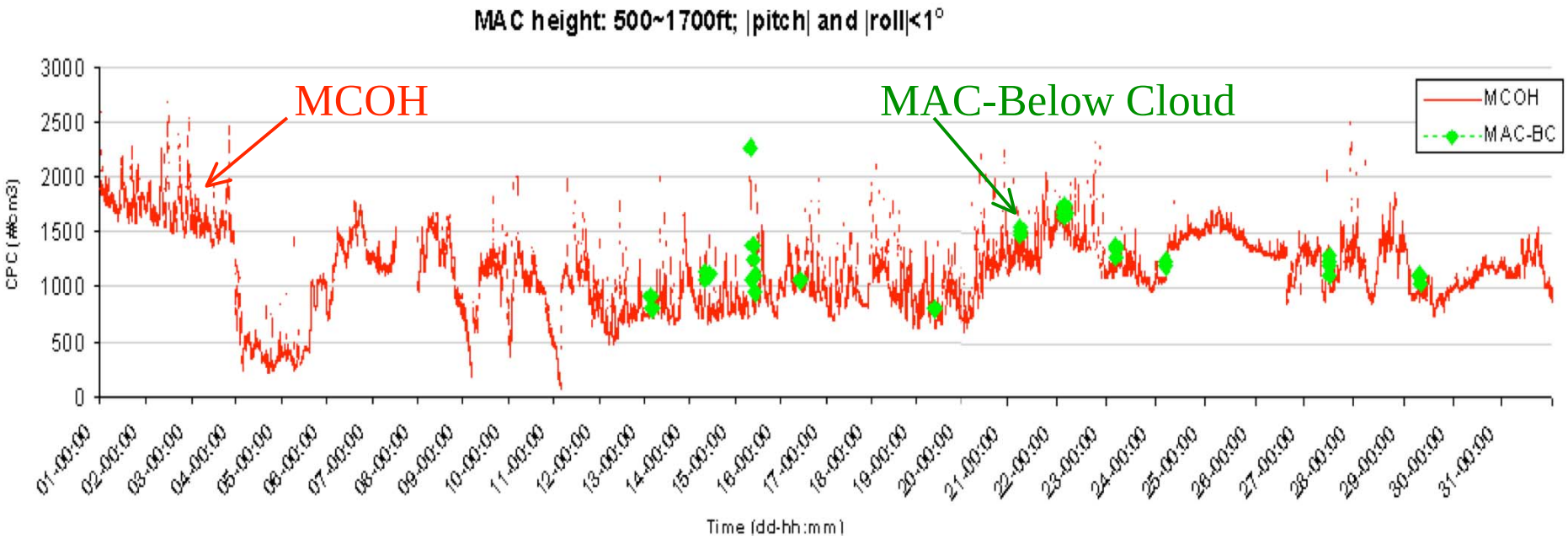
Beginning of Dust Events

March 23 2006
850 mb winds

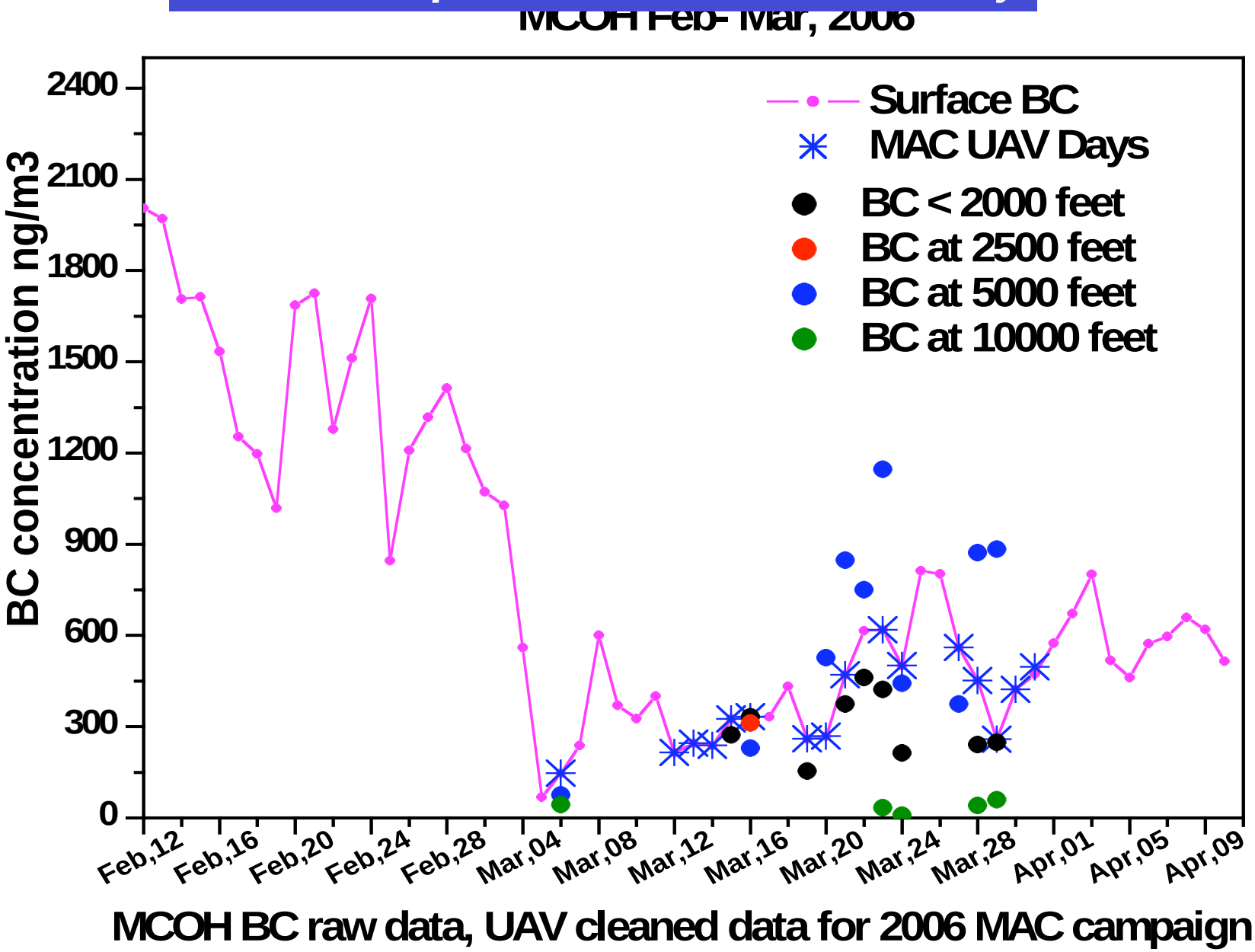
Validation 1, with Ground Observations

Validation of Total Aerosol Concentrations

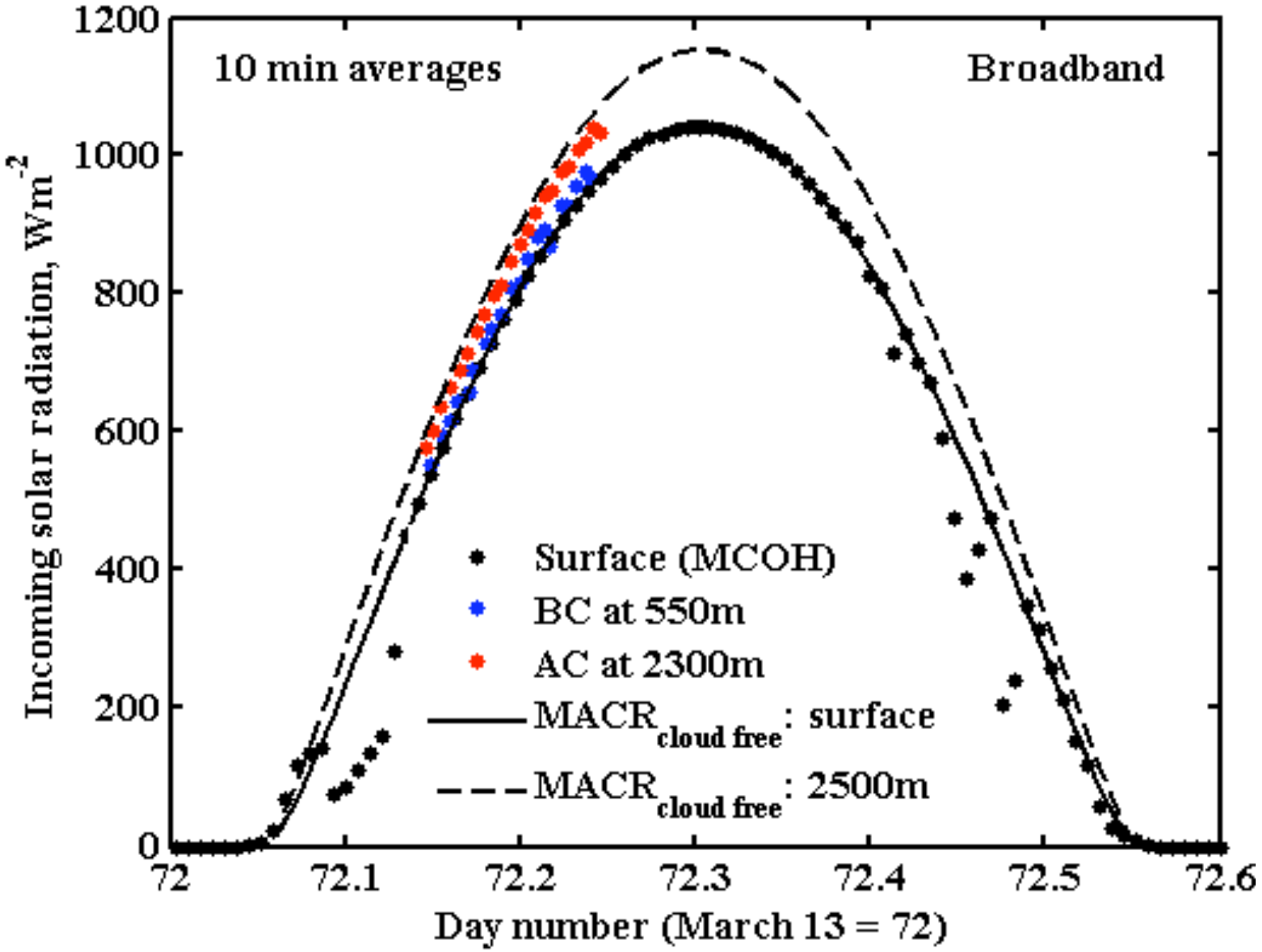
CPC : MCOH vs MAC; Mar 01-31, 2006



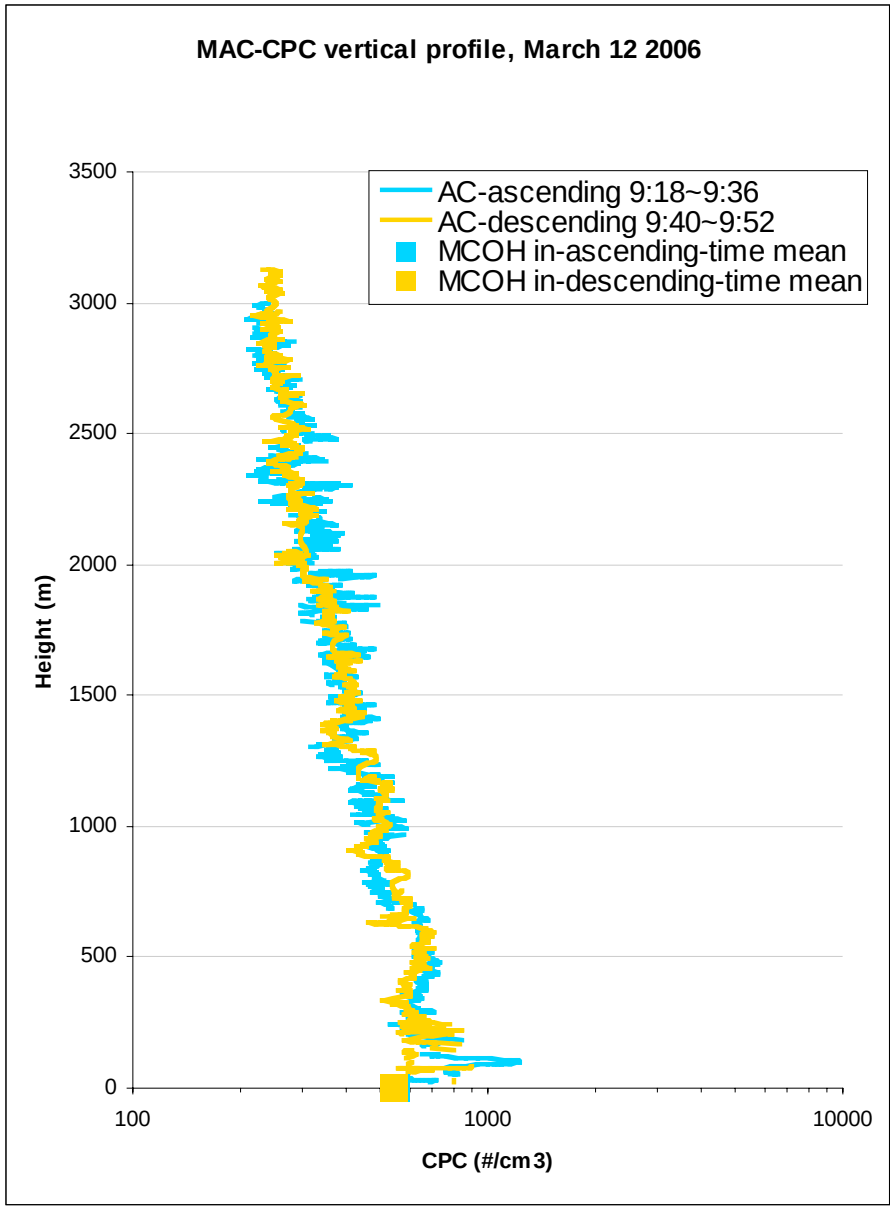
Validation of Black Carbon Mass Density



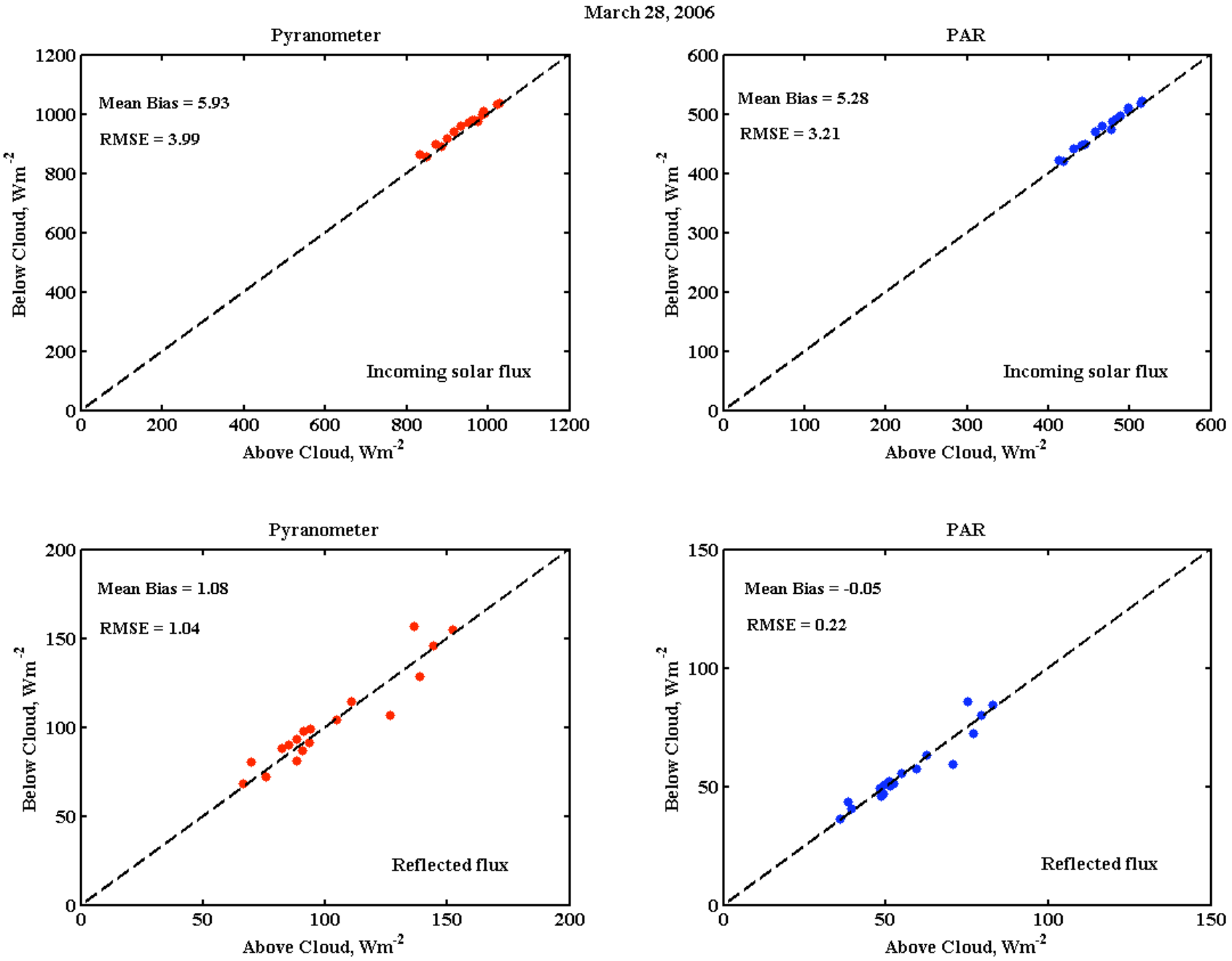
Comparison of Solar Radiation Fluxes



Validation 2-
Consistency and Repeatability of Measurements:
UAV to UAV comparison

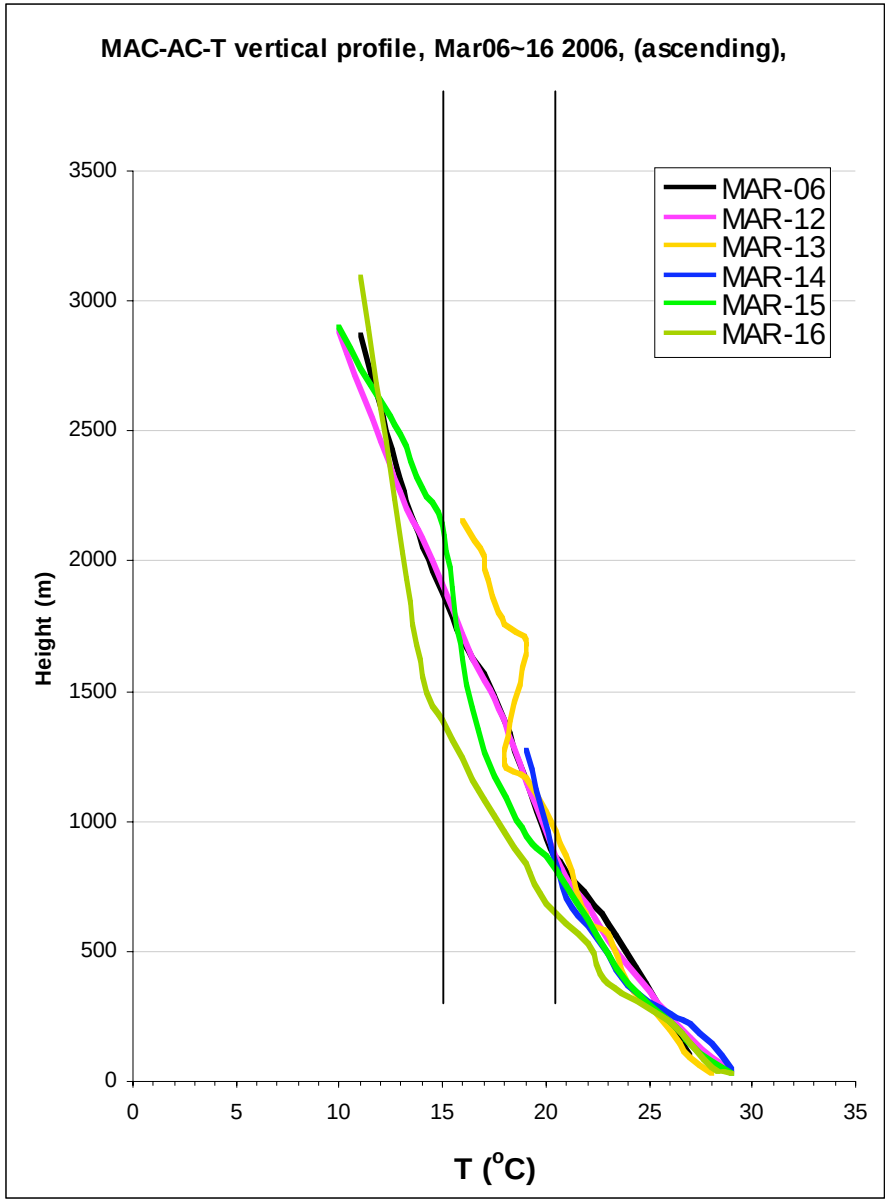

MAC-CPC vertical profile, March 12 2006
AC-ascending 9:18~9:36
AC-descending 9:40~9:52
MCOH in-ascending-time mean
MCOH in-descending-time mean
Height (m)
3500
3000
2500
2000
1500
1000
500
0
100
1000
10000
CPC (#/cm3)

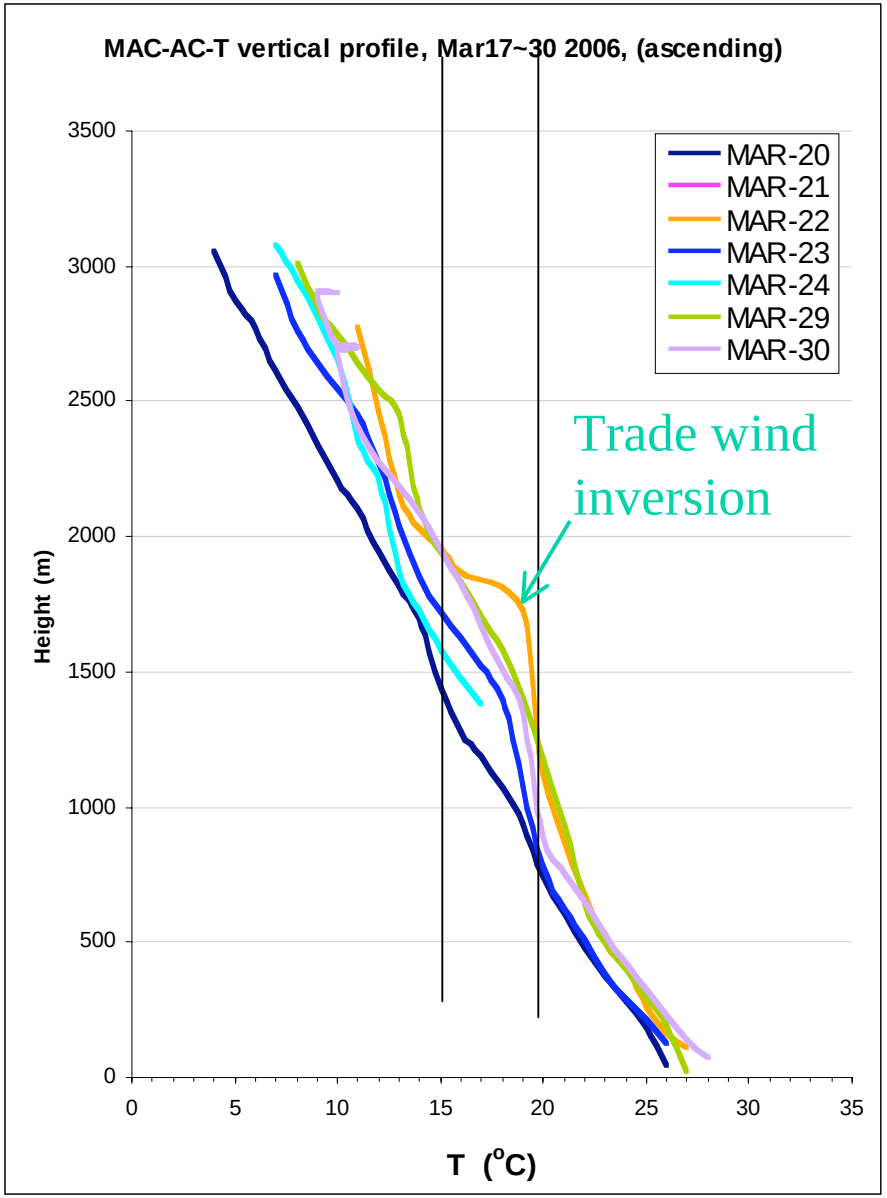
Wing to wing comparison – March 28, 2006



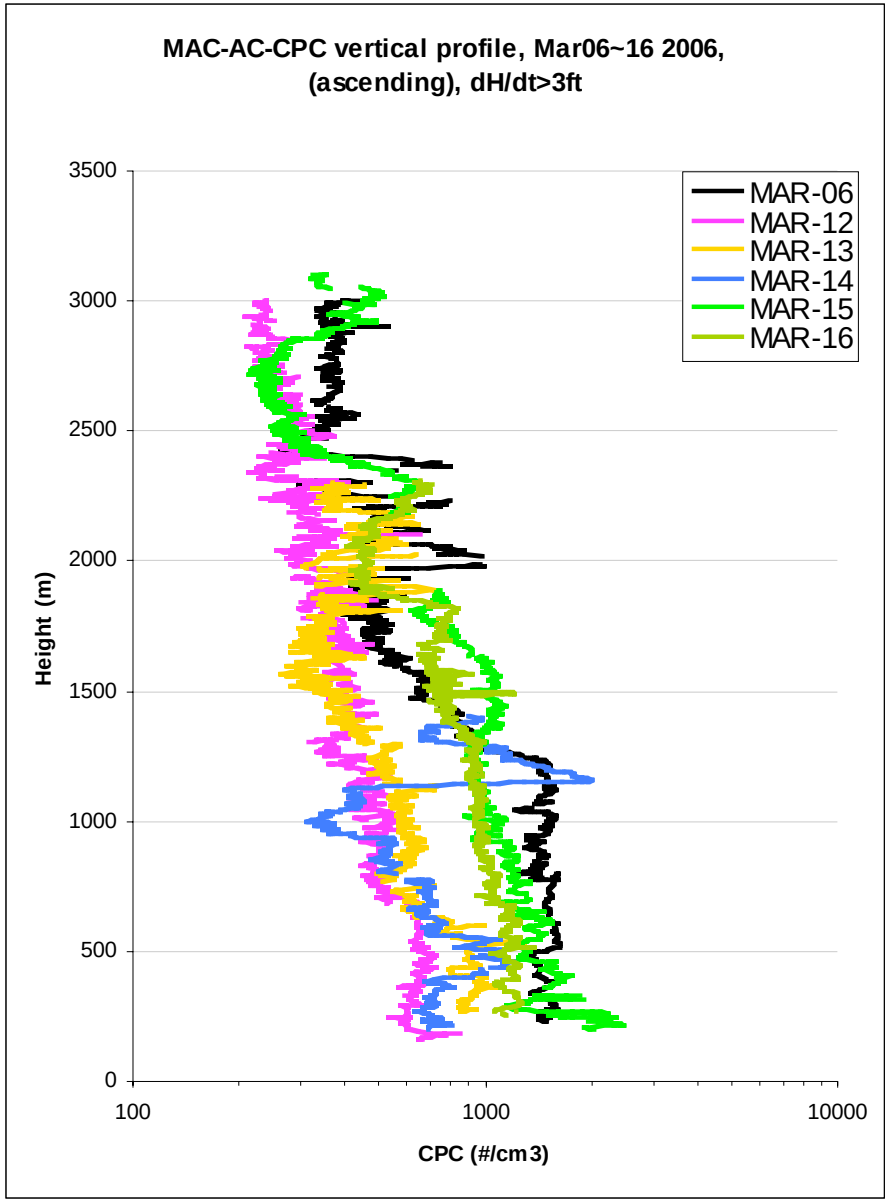
Preliminary Scientific Findings

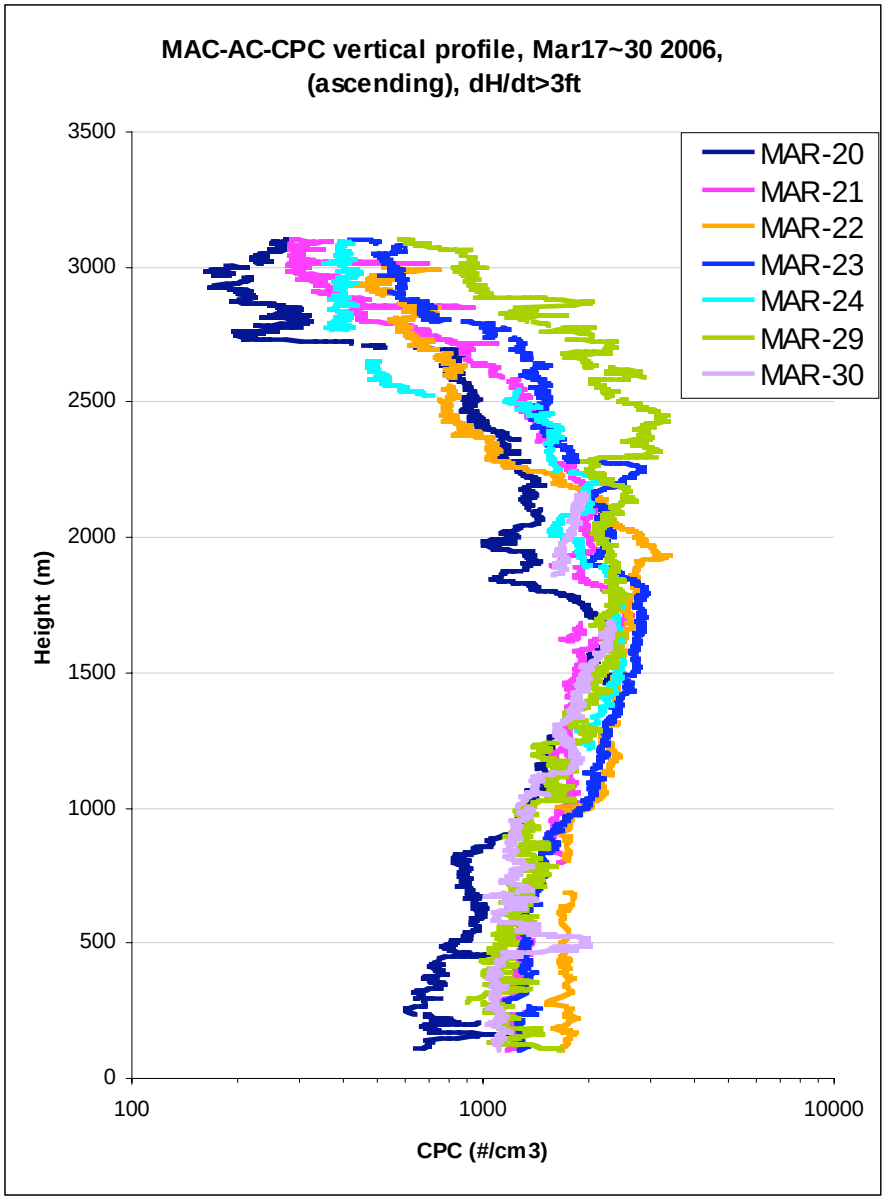
Vertical Profiles of Air Temperature



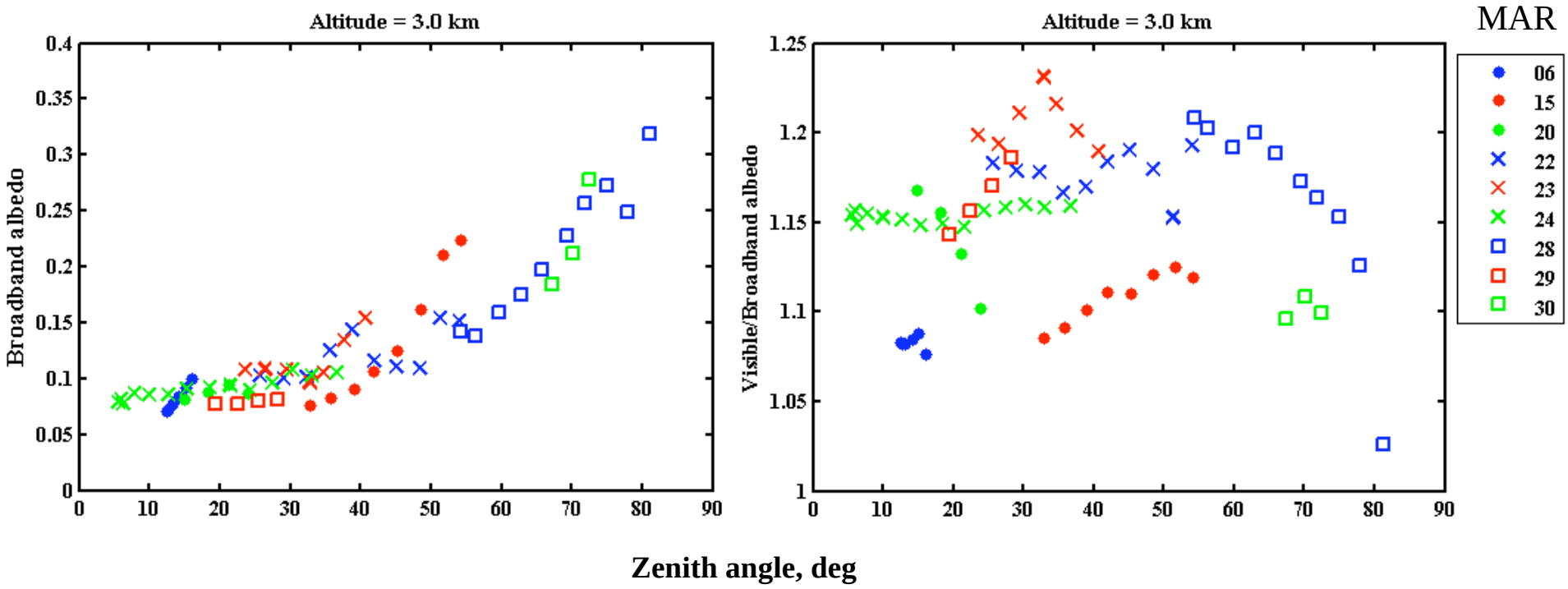


Vertical Profiles of Aerosols

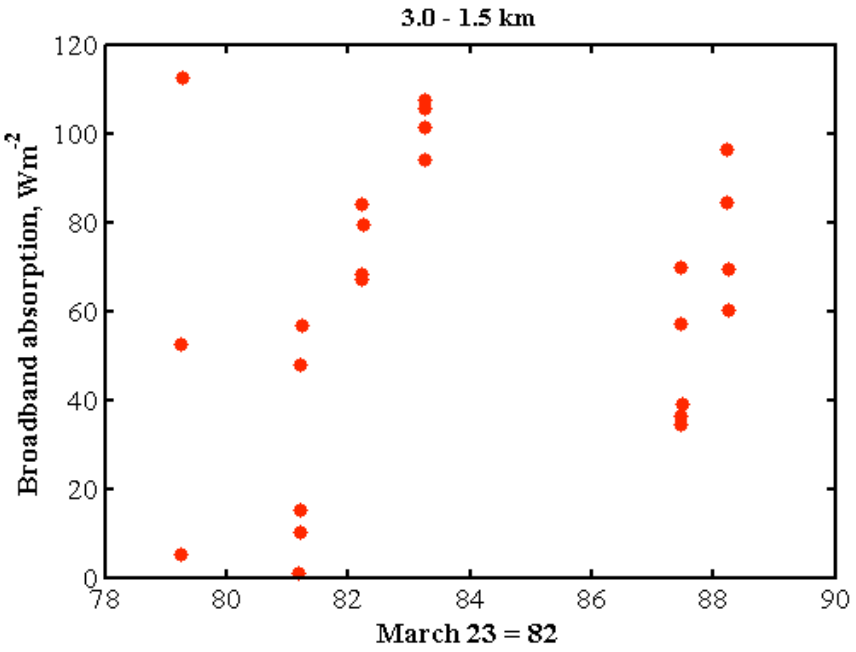


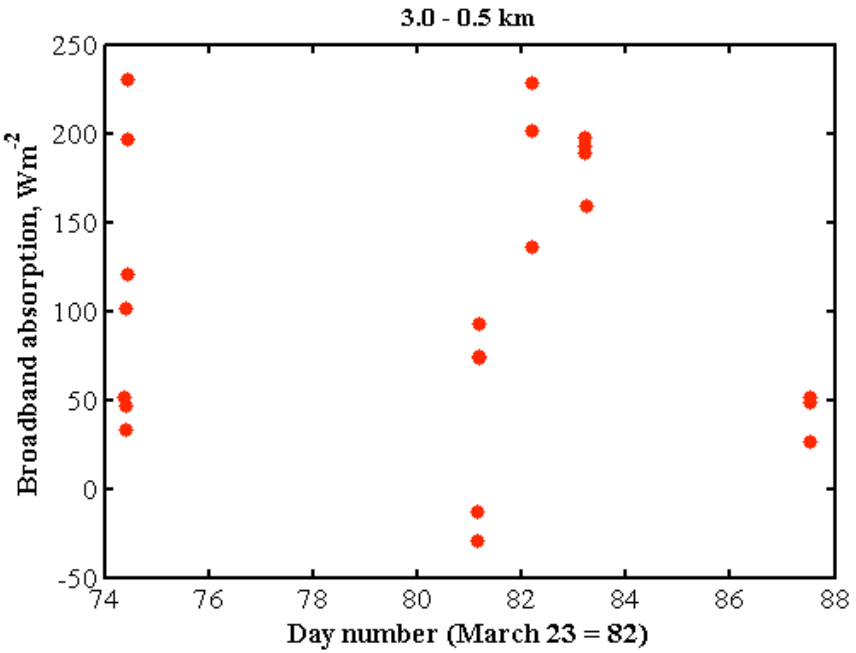


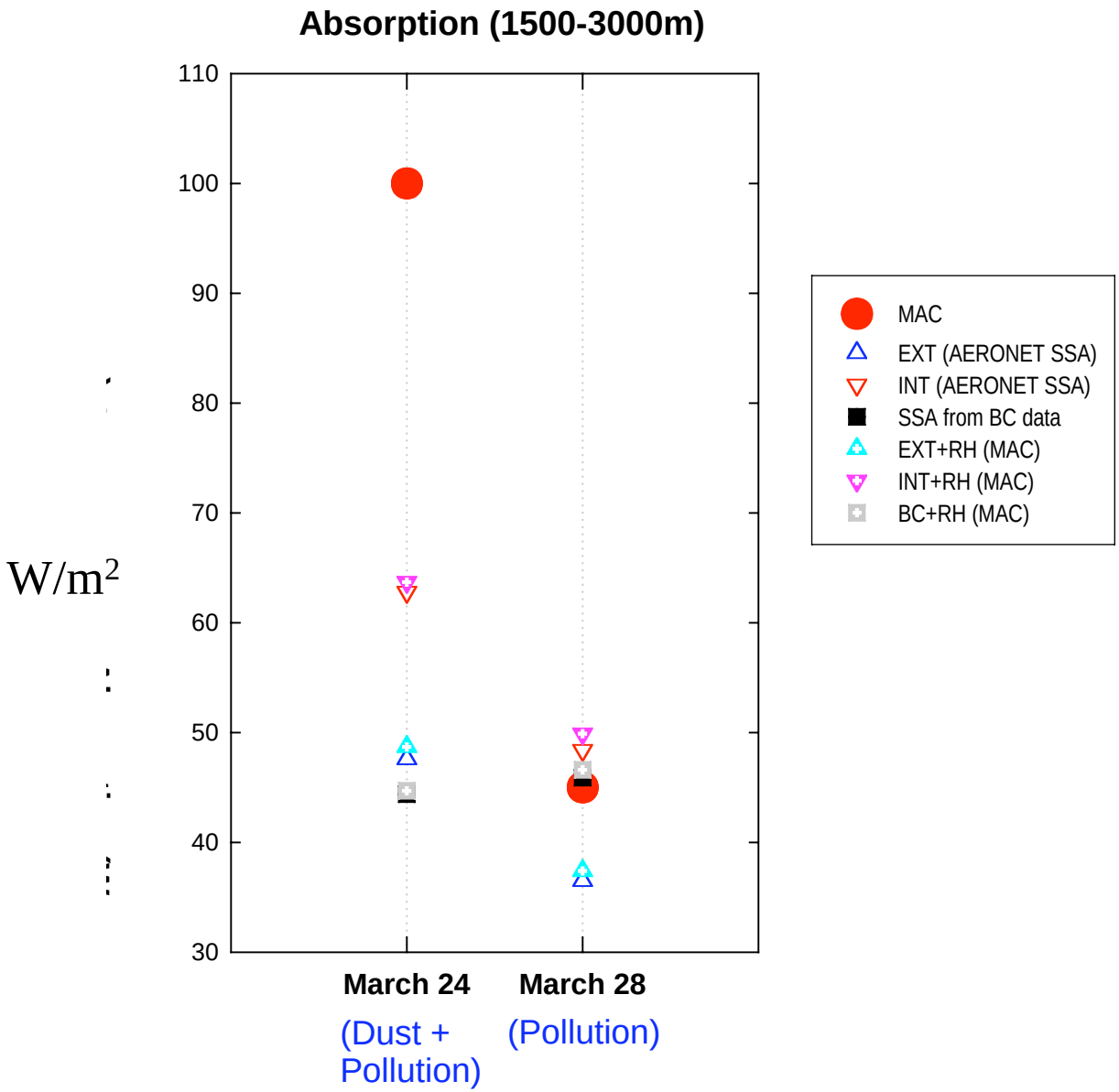
Broadband & Visible Albedo



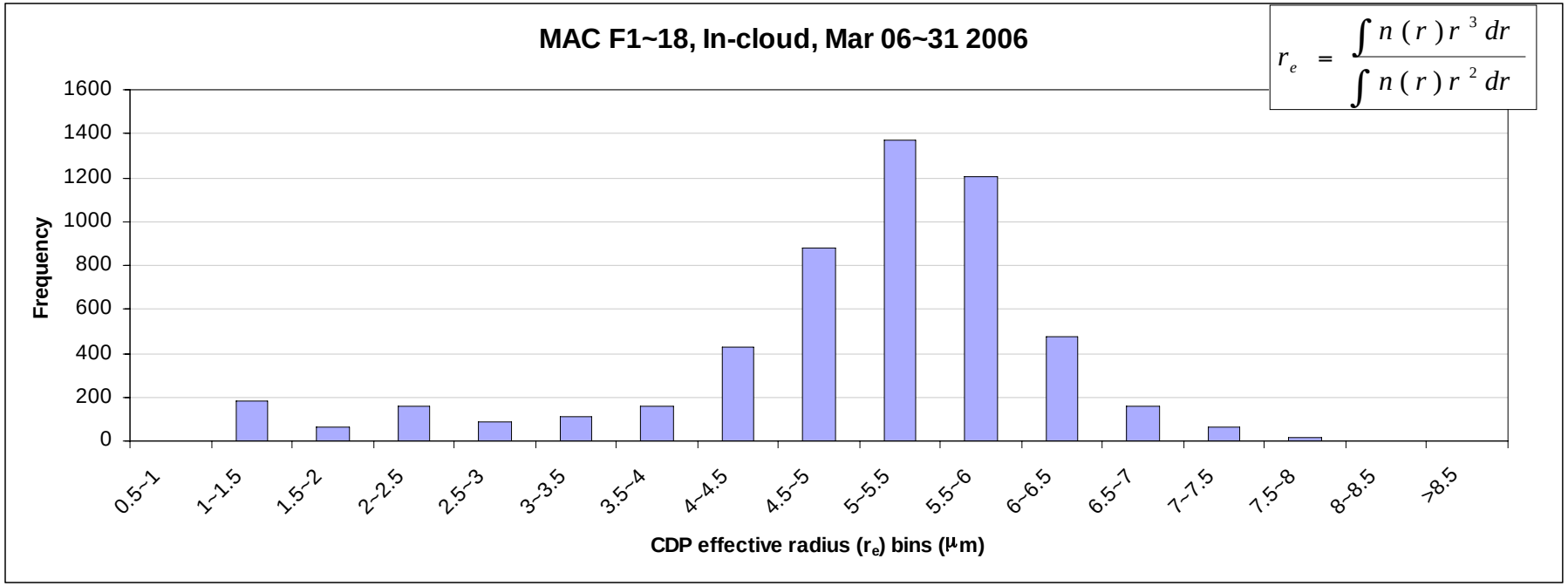
Direct Measurements of Solar Absorption







*RH: Measured Temperature and Humidity profile by MAC



Statistics of Cloud Microphysics, *averaged over all flights*

Next Step in the UAV System: A Proposal

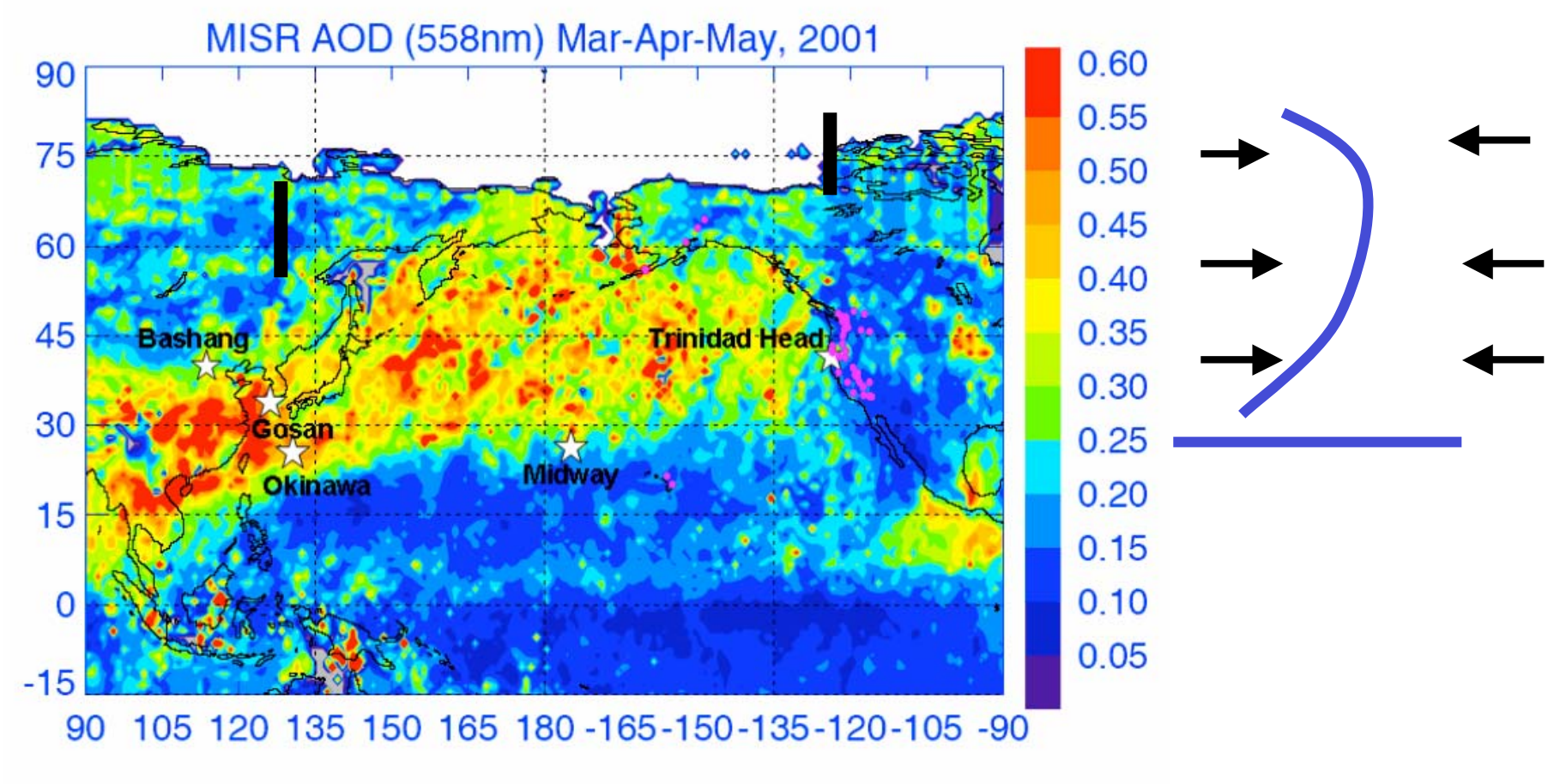
I. Bring in Advanced Technology in Miniaturization and Multiple UAV operations.

Integrate MEMS, NANO-Technology and Sensor Networking

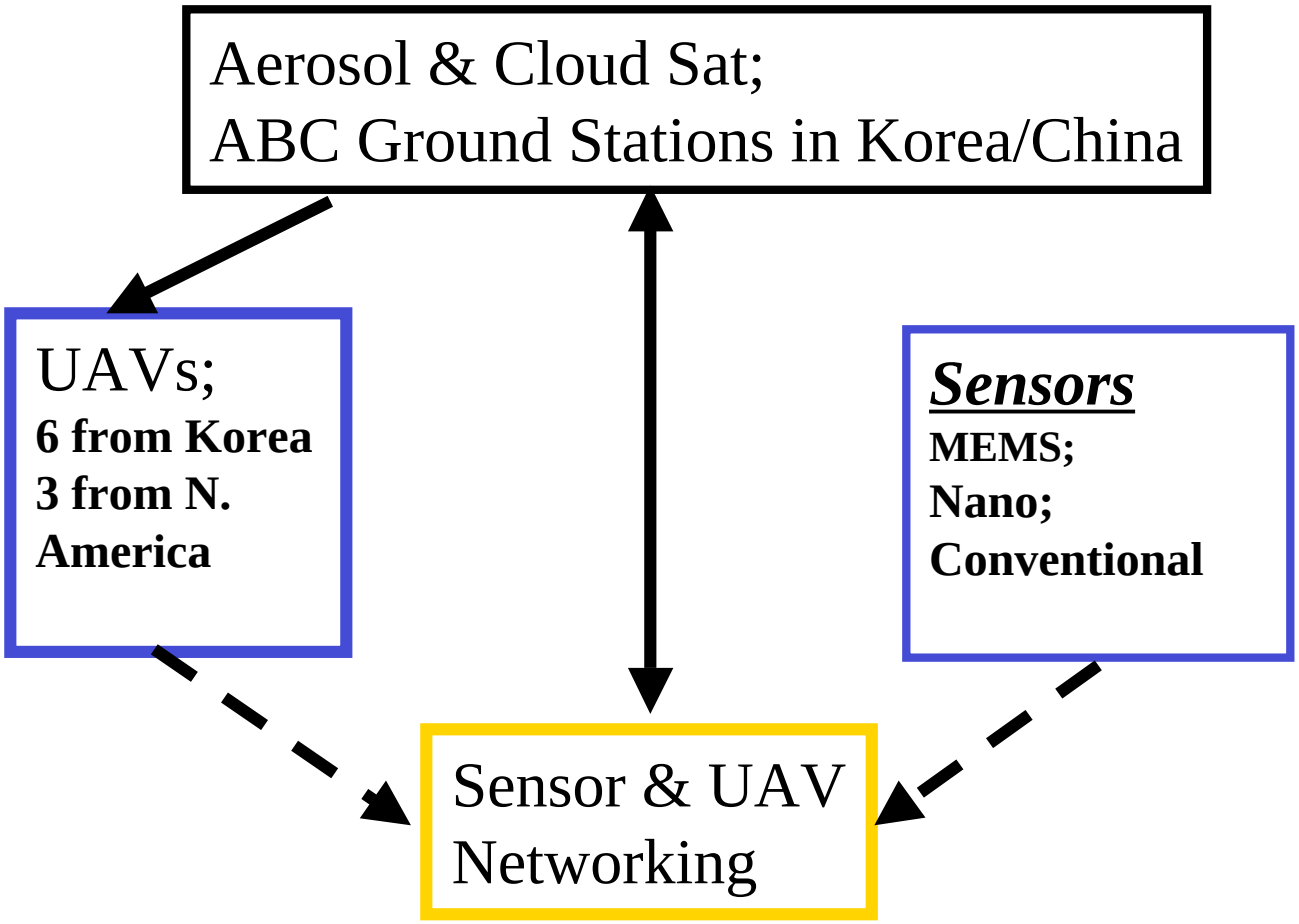
II. Address an outstanding and Major Issue in Reducing Uncertainty in Climate Forcing & Long Range Transport of Air Pollution

Role of Dust Mixed with Pollution: Mongolian_Gobi Dust Mized with East Asian Pollution & Transported Across the Pacific Ocean

III. When? April 2008; Where: 6 UAVs from S. Korea and 3 UAVs from Midway or N. California


MISR AOD (558nm) Mar-Apr-May, 2001
90
75
60
45
30
15
0
-15
90 105 120 135 150 165 180 -165 -150 -135 -120 -105 -90
Bashang
Gosan
Okinawa
Midway
Trinidad Head
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05

UAV_ Sensor Observing Systems Technology



Thank You

1) **NSF/NOAA/NASA/Vetlesen/Alderson**
2) **Maldives Government**
3) **Fahey/Fein/Koblinsky/Kuettner/Maring/Yuhas**
4) **NASA-Dryden (Curry/Jennison)**
5) **ACR Team: Patterson/Mulligan/ Flight Crew**